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Trends of Research and Development of Dye-Sensitized Solar Cells

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1 Introduction

Efforts to establish a low-carbon society have been initiated by reducing dependence on fossil fuels including petroleum, coal, and natural gas, based on such renewable energy as sunlight and wind power. As part of the effort, the Agency for Natural Resources and Energy (ANRE) has set out a goal to significantly increase the extent to which solar power generation is introduced in Japan tenfold by 2020 and 40-fold by 2030.[1] With a goal to develop solar power generation as a major energy source by 2030, the New Energy and Industrial Technology Development Organization (NEDO) has created the Photovoltaic Roadmap Toward 2030 (PV2030), a guideline for technological progress in Japan. Aiming to develop photovoltaic generation as a principle technology to support CO_2 reduction by 2050 with a contribution to not only Japan but the global community as well, PV2030 has also been revised to further promote the use of photovoltaic generation and maintain the Japanese industry's international competitiveness (PV2030+[2]). To promote the use of photovoltaic generation, PV2030+ aims to accomplish the following:

1) Improved cost efficiency of solar cell modules, including cost reduction

Develop technologies for manufacturing solar cell modules and high performance system devices at low costs. Inexpensive system design. Simplified installation work. Extend the system life to further improve cost efficiency.

2) Transformation into usable energy for the sake of expanded use and applications

Establish system-use technologies for eliminating the mismatch between generation and power demand through interconnection with system power and combination with batteries. Establish reliability as an industrial product.

3) Fostering of social infrastructures, use infrastructures, and use environment

Build a recycling and reuse framework. Design systems through government-business cooperation.

4) Industrial evolution and international competitiveness

Promote the procurement of raw materials in overseas markets. Develop overseas production bases. Foster human resources.

In addition to these challenges, research and development have been desired of new concepts such as a quantum dot and new structures such as a tandem structure. Ultra-high-efficiency solar cells with light-collecting and other new systems have also been anticipated.

This report introduces the trends of research and development for dye-sensitized solar cells, of which Japan has particularly strong capabilities and which have color variations, cost advantages, and other features that are not found in other types of solar cells, in light of promoting the extent to which photovoltaic generation is generally introduced, as mentioned previously.

2 Current Situation of Dye-sensitized Solar Cells

2-1 Comparison of Solar Cell Materials

Table 1 shows the types and characteristics of solar cell materials for comparison. In terms of energy conversion efficiency and long-term reliability, the mainstream solar cells at present are silicon-based. For the sake of promoting the extent to which photovoltaic

Table 1 : Types and Characteristics of Solar Cell Materials (Comparison of Single-Junction Cells, as of May 2009)

Type	Material	Structure/ process	Measured conversion efficiency (%)[3]	Cost competitive-ness	Advantages	Disadvantages (Necessary improvements)
Si-based	Single-crystal Si	n-type Si layer doped on single-crystal p-type Si layer	25.0	×	High efficiency, high reliability	Not suited for mass production; High cost, variable raw material price, little room for improvement in conversion efficiency
	Polycrystalline Si	n-type Si layer doped on polycrystalline p-type Si layer	20.4	△	Lower cost than single-crystal Si; High efficiency, high reliability	Lower efficiency than single-crystal Si; Variable raw material price
	Amorphous Si	p-layer, i layer, and n layer deposited by CVD process	9.5	△	Relatively small use of Si material; Lower cost than single-crystal Si	Lower efficiency than single-crystal Si; Light degradation
Compound-based	GaAs	Metal-organic CVD	26.1	×	High efficiency; Endure radiations in space	Low deposition rate; Using toxic As; High cost
	CdTe	p-type CdTe polycrystalline layer on n-type CdS layer	16.7	△	A variety of production methods; Optimum band gap for generation; Lower cost than single-crystal Si	Using highly toxic Cd; Dependent on the amount of Te resources
	CIS/CIGS	Vapor deposition of CIS/CIGS layers	19.4	△	High optical absorbance	Dependent on In resources
Dye-sensitized	Dye, semiconductor, electrolyte	Place dye-absorbed TiO_2 electrode in electrolyte	10.4	○	Capable of production by simple process in open air; Colorable, transparent; Maintain generation characteristics under room light etc.	Ultraviolet degradation
Organic thin film based	Fullerene, polymer	Apply mixture of p-type polymer and n-type fullerene etc.	5.2	○	Little thickness; Capable of manufacturing by inexpensive application process	Ultraviolet degradation; Low efficiency

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generation is used in the future, the challenge is to reduce the material and process costs significantly from the current 46 yen/kWh. Crystalline silicon solar cells are used in large quantities, but have a unstable cost factor, namely price fluctuations due to material supply. The problem with amorphous silicon solar cells is low energy conversion efficiency. Non-silicon compound semiconductors are under development, whereas such materials have essential problems, including resource depletion and toxicity in the long term.

Unlike the foregoing cells, dye-sensitized solar cells have the following advantages:

1) Capable of production in a simple way

No vacuum process is required for manufacturing. The solar cells and panels can be produced in a simple way in open air. This means a significant cost reduction of 1/5 to 1/10 as compared to silicon solar cells.

2) Colorable, transparent

The use of dye and its wide selection allow colored cells and transparent cells.

3) Flexible thin structure

Using aggregates of fine particles of photoelectric conversion materials, the solar cells can be formed as flexible thin films.

4) Generation characteristics insusceptible to the incident angle and intensity of the sunlight

Generation characteristics can be maintained even in a weak light condition, such as under faint light in the morning and evening and when indoors.

5) Lighter weight

Plastic substrates can be used to reduce the weight of solar cells and panels.

With these advantages, dye-sensitized solar cells can be installed in locations where appearance is important and other solar cells are hardly applicable, such as the glass panes and inner and outer walls of a building, the sunroof and outer panels of an

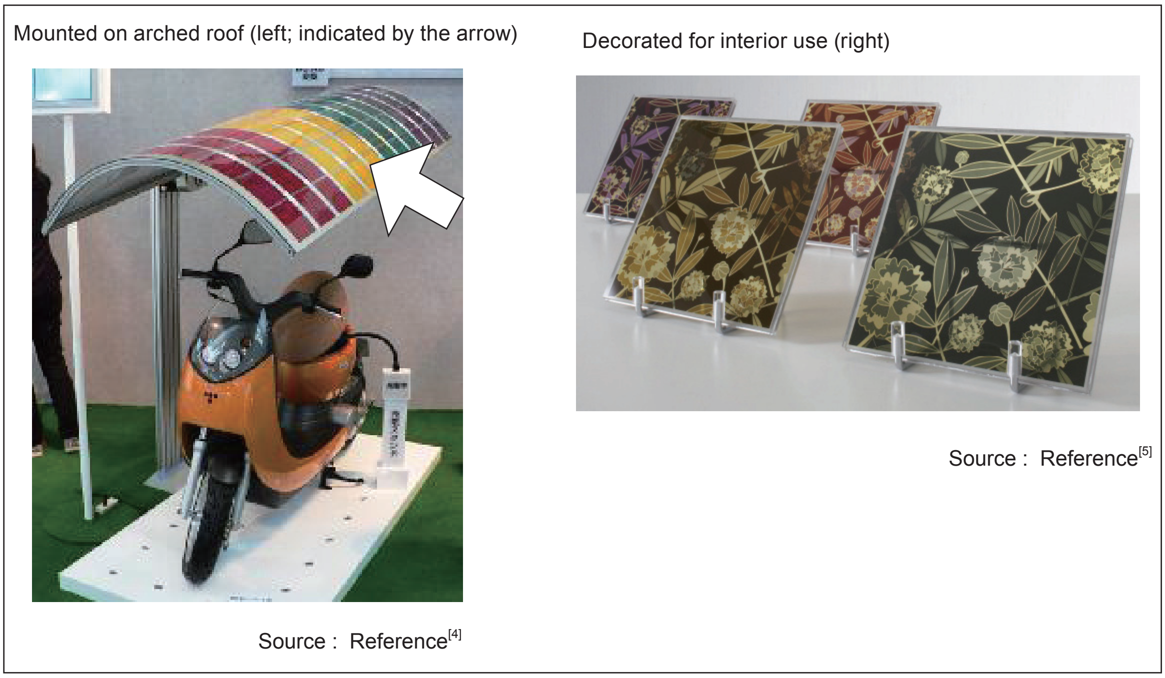

Figure 1 : Prototype Models of Dye-Sensitized Solar Cell Panels

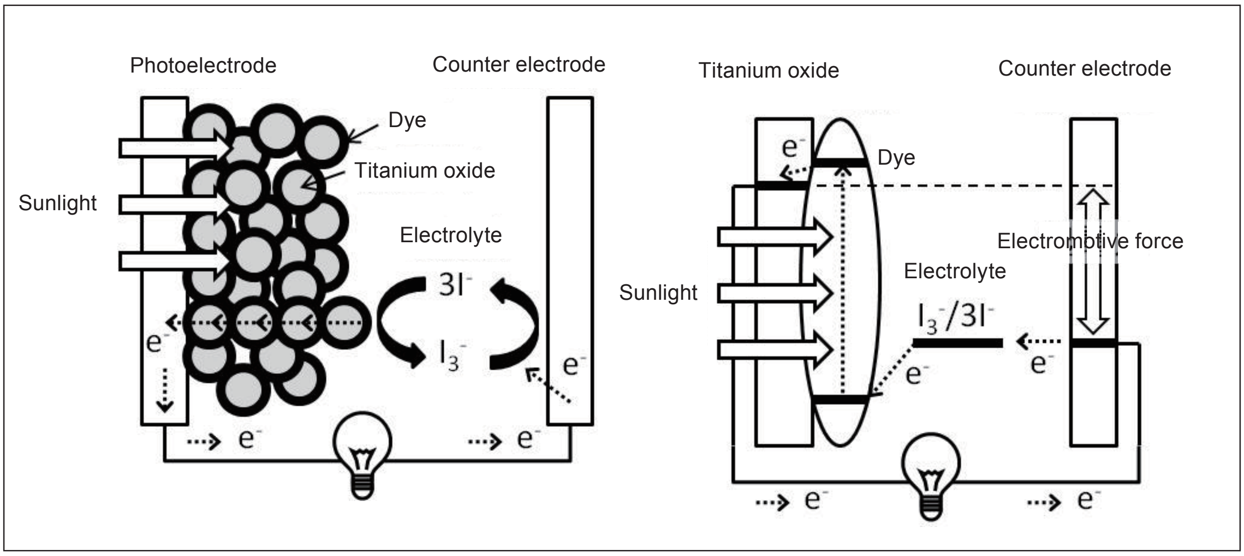

Figure 2 : Cell Structure (left) and Principle of Operation (right) of Dye-Sensitized Solar Cell

Prepared by the STFC based on Reference[7]

automobile, and the enclosure of a cellular phone. This allows the creation of new markets with expanded demand. Figure 1 shows examples of prototype models for dye-sensitized solar cell panels. Such panels can be installed on the colored arched roof of a garage, taking advantage of the excellent design and drainage performance. The panels can be variously freely decorated for room walls, windows, and interior use.

2-2 Trends of Dye-Sensitized Solar Cells

2-2-1 Principle of Operation

A dye-sensitized solar cell is one of the solar cells that uses organic dyes to gain photovoltaic force. It is also called a Grätzel cell after the inventor, a professor of the Swiss Federal Institute of Technology in Lausanne (EPFL: Ecoles Polytechniques Fédérales de Lausanne).

Figure 2 shows the cell structure and the principle of operation for the dye-sensitized solar cell. The light incident on the transparent electrode (photo-electrode) excites the dye in the cell from the ground

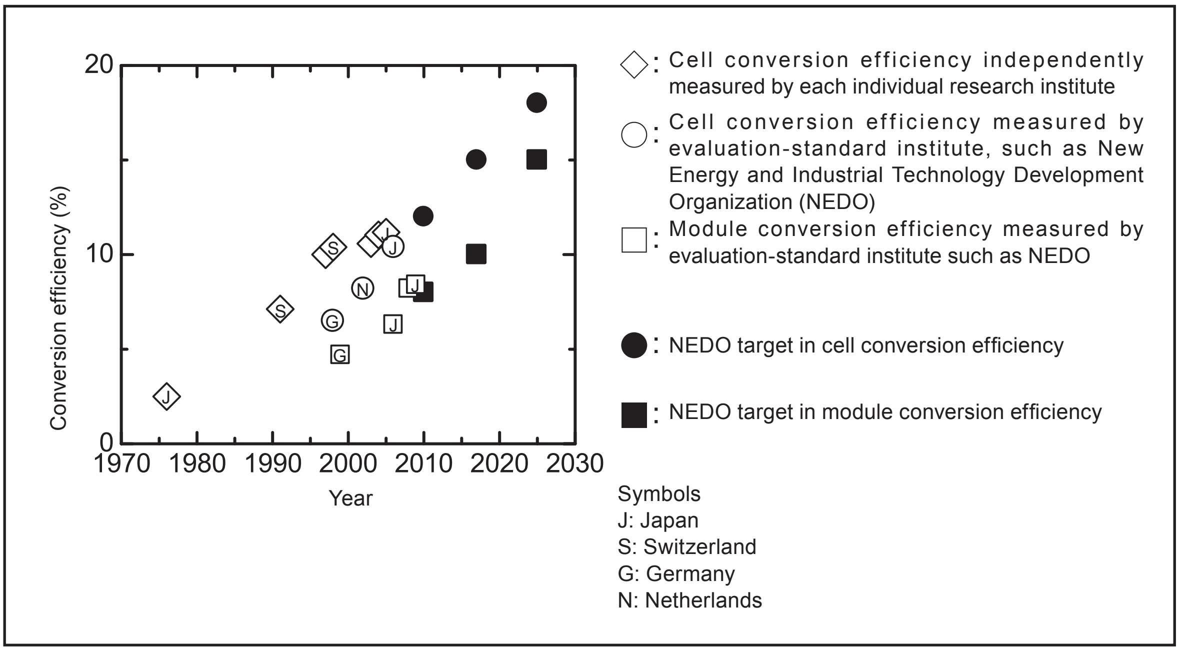

Figure 3 : Changes in Conversion Efficiency of Dye-Sensitized Solar Cell and Future Goals of Research and Development

Prepared by the STFC based on References[2,3,12-16]

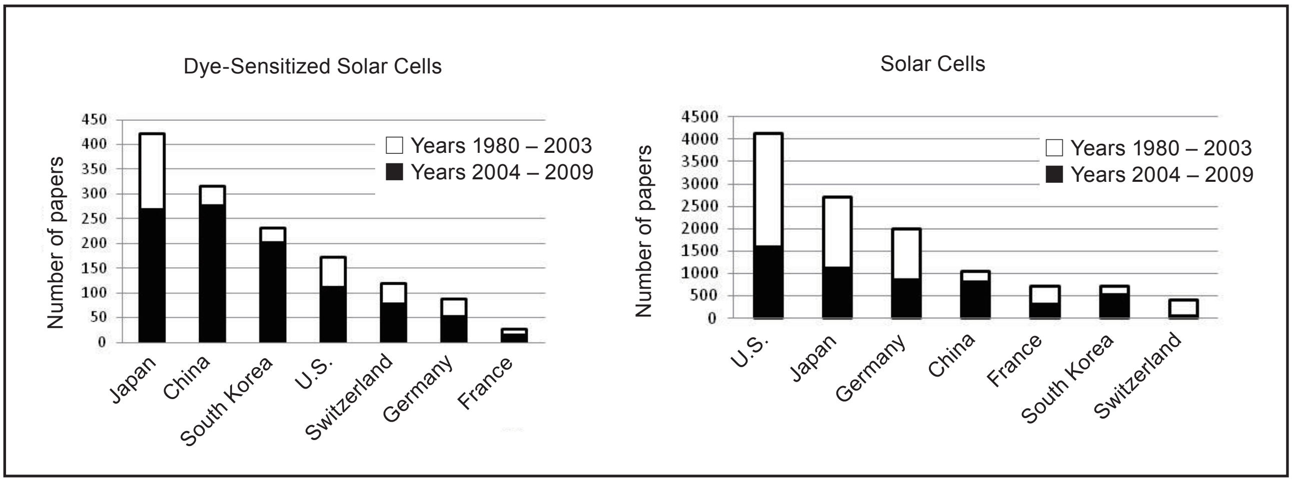

Figure 4 : Numbers of Papers on Dye-Sensitized Solar Cells and All Solar Cells by Country (Major Countries)

Prepared by the STFC

state to an excited state, whereby an electron (e^-) is formed. The e^- passes through titanium oxide (TiO_2) to reach the transparent electrode, and flows into the external circuit. Meanwhile, the loss of e^- in the dye is supplemented with iodine ions ($3I^-$) in the electrolyte. At this point, $3I^-$ are transformed (oxidized) into iodine ($I_3^- = I_2 + I^-$), and then return to $3I^-$ (reduction) by receiving e^- that is supplied from the counter electrode. Such an electron transfer has been accounted for in terms of the energy level and electron transfer rate. The former provides the explanation that the energy level of the conduction band of titanium oxide and the redox level of iodine ions and iodine should be situated between the excited level and ground level of the dye molecules, so that electrons are moved by a phenomenon similar to that of water flowing from a high to low level. In the latter point of view, the main electron transfer proceeds preferentially because the electron transfer rates in the respective reaction processes are more than 10 times higher than in the reverse reactions and sub reactions. Suppose that sunlight that had a higher energy than the difference between the ground level and excited level of the dye is supplied and converted into as much electricity as possible. In such cases, the theoretical calculation of the energy conversion efficiency is 33%.[6]

2-2-2 History of Research and Development

In the early 1970s, research was conducted on photosensitizers for photographic use. The research involved the absorption of dye on oxide semiconductors for the purpose of quantifying the dye-based spectral sensitization phenomena. This paved the way for the extraction of a photocurrent to an external circuit through the electrodes.[8] The first dye-sensitized solar cell present to the world, a cell from which an electric current can be taken out based on the electromotive force between the two electrodes, was developed in 1976 by Professor Tsubomura et al. at Osaka University, using porous zinc oxide as the dye support. The energy conversion efficiency was 2.5%.[9] In 1991, Professor Grätzel et al. at EPFL, Switzerland, presented a prototype of the current dye-sensitized solar cell, which had an improved conversion efficiency of 7.12%.[10] The findings of the Grätzel's research are characterized as follows:

1) Titanium oxide nanoparticles were used to increase the dye absorption area to a large scale.
2) Ru-based dyes with a wide range of optical absorption were developed.
3) A cell structure with relatively small loss of conversion efficiency was devised.

Research efforts continued as will be described in the chapter on technological trends. In the first half of 2009, the maximum cell conversion efficiency in actual measurement was 11.2% (announced by Sharp Corporation) and the maximum module efficiency was 8.4% (announced by Sony Corporation). Figure 3 shows the past changes in the conversion efficiency and future goals of development.

Since 2008, module efficiencies of above 8% have been reported, already exceeding the development goal as of 2010 in NEDO PV2030+.

The most reliable evaluation values on the conversion efficiencies are presented by authorizing institutes with the industrial standard, such as the National Institute of Advanced Industrial Science and Technology (AIST), whereas numerical values independently obtained by individual research facilities are often accepted. Figure 3 shows both values. At present, practical-sized products with a conversion efficiency of 8%, accompanied by reliable manufacturing techniques, are considered to be the minimum requirement for the market. According to estimates, a module conversion efficiency of 15% allows generation cost as low as 7 yen/kWh.[11] The technological challenges and measures for achieving the goals of development of the cell and module conversion efficiencies in the future will be described in Section 3-2.

2-2-3 Comparison Between Japan and the World

In this field of research and development, EPFL, led by Professor Grätzel, and several Japanese research institutes are leading the world. EPFL excels at approaches based on basic research methods, such as a laser spectroscopic analysis, semiconductor theories, and dye molecular orbital calculation. The Japanese research institutes are successful in pursuing applied research methods, such as the development of dyes and cell devices in collaboration with private companies, universities, and independent administrative institutions. At present, Japanese research achievements provide the world's highest records both in the cell and module conversion efficiencies. Japan is also leading the world in developing quasi-solid electrolytes and plastic substrates, which are major technological challenges for the future. Due to the following factors, Japan has been in the leading position in research and development of dye-sensitized solar cells:

1) The internationally high capabilities of research and development in the fields of nanotechnologies and materials.[17] In electrochemistry, basic researches on photo-electrochemistry, including the Honda-Fujishima effect, have been rich in both quality and quantity.
2) The advantages of the Japanese monozukuri (basic manufacturing) technologies[18] have been utilized in manufacturing photo-electrodes and cells.
3) There have been national projects in which researchers from different research institutes gather to collaborate. The results of development of the respective technologies have been successfully merged with the original technologies of their own research institutes for further improvement.

Figure 4 shows the number of papers on dye-sensitized solar cells and all solar cells from each major country, from 1980 to 2003 and since 2004. These results were obtained from the Thomson Reuters' ISI Web of Knowledge database, with the search keywords "dye-sensitized solar cell" and "solar cell." Japan has more papers on dye-sensitized solar cell than on any other solar cells. The reason is that more than one university, public research organization,

Table 2 : Major Publicly Funded Research Programs on Dye-Sensitized Solar Cells

Country/region	Program/project	Period
Japan	NEDO: Research and Development of Photovoltaic Generation System Technologies	Years 2006 – 2009
	JST: Basic Research Program "Creative Research for Clean Energy Generation Using Solar Energy"	Years 2009 – 2016
Europe	FP7 : ROBUST DSC project	Years 2007 – 2010
U.S.	DOE: Solar Energy Technologies Program	Years 2007 – 2011

NOTE) FP7: The E.U. 7th Framework Programme for Research
DOE: Department of Energy

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and private company published the papers. In recent years, papers from China and South Korea have been increasing sharply. This appears to be due to positive investment in this field of research[19] and the background of the monozukuri technologies as in Japan.

Table 2 shows major publicly-funded research programs in Japan, the United States, and Europe. Dye-sensitized solar cells are regarded as next-generation solar cells close to practical use, and given research grants in all of Japan, the United States, and Europe.

In regard to commercialization, G24 Innovations (U.K.) and Solaronix SA (Switzerland) have already released commercial products. Dyesol (Australia) has been making efforts toward commercial production, including the delivery of modules to public organizations. Konarka Technologies, Inc. (U.S.) aims to prepare flexible products for the market. In Japan, Nissha Printing Co., Ltd. has announced that it will ship out samples in 2010,[20] but has yet to reach commercialization. Prototype models have been released by Aisin Seiki Co., Ltd., Toyota Central R&D Labs., Inc., Fujikura Ltd., Sony Corporation, TDK Corporation, Rohm Co., Ltd., Hitachi Maxwell, Ltd., and Peccell Technologies, Inc. The development for practical use is continuing. Because Grätzel's basic patent (Switzerland) expired on April 12, 2008, efforts toward commercialization and practical use are expected to be more active in the future.

3 Trends of Research and Development of Dye-Sensitized Solar Cells

3-1 Component Technologies

Research and development of the respective technologies of dye-sensitized solar cells will be described for a total of six items, including the four major parts of the cell structure shown in Figure 2 and two articles on device configuration.

(1) Photo-electrode

As mentioned above, one of the characteristics of the Grätzel cell is that the photo-electrode is made of nano particles of titanium oxide (TiO_2) with a porous structure as the support for dye absorption. Layers of titanium oxide with different particle sizes can be stacked to provide a light confinement effect (Professor Arakawa et al. at Tokyo University of Science). This has been combined with the light scattering from star-shaped particles of titanium oxide to provide a cell conversion efficiency of above 10% (Sumitomo Osaka Cement Co., Ltd.).[11] An improvement of the conversion efficiency over a wide range of wavelengths by $TiCl_4$ surface treatment (Grätzel et al.) has been reported.[21] Research has also been made to improve the conductivity of TiO_2 through morphological control, such as the formation of nanotubes, as well as to coat the surface of TiO_2 with a different type of oxide, such as niobium oxide (Nb_2O_5), thereby suppressing electron leakage from the titanium oxide to the electrolyte solution. Research papers have been published for oxide semiconductor materials other than titanium oxide and composite materials with other oxide semiconductors for the sake of improved charge separation efficiency. Such efforts, however, have not been successful in providing characteristics superior to those of simple titanium oxide. As for the method of manufacturing the photo-electrode, the uniform formation of the electrode is essential to favorable characteristics. After various attempts, screen printing is considered to be suitable in terms of mass production.

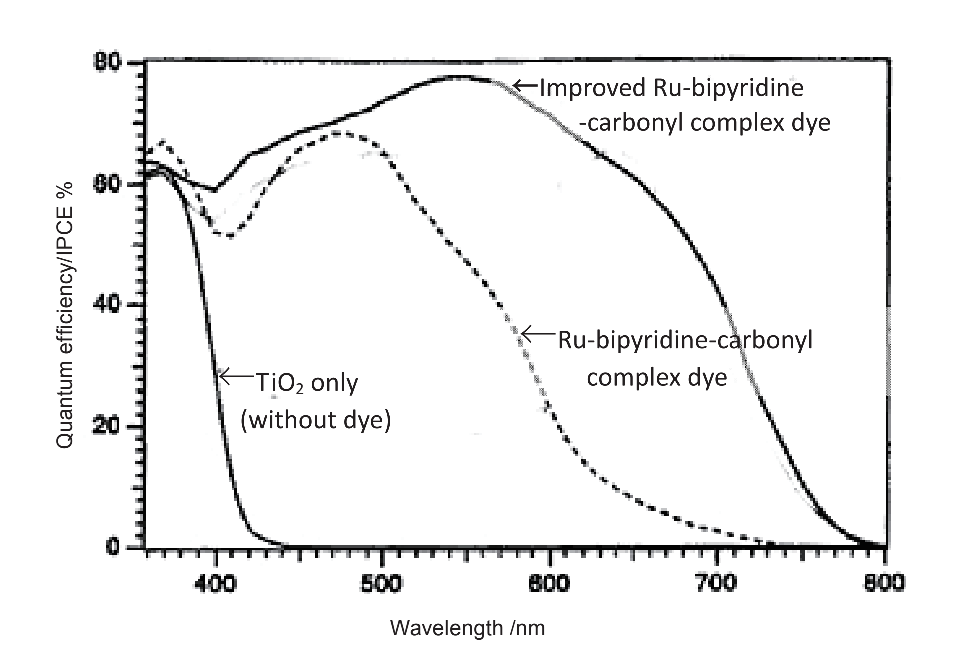


Figure 5 : Action Spectrum of Dye-Sensitized Cells With Different Ruthenium (Ru) Dyes

Prepared by the STFC based on Reference[22]

(2) Dye

Dye-sensitized solar cells use the dye to expand the available range of wavelengths in the spectrum of sunlight. The dye therefore plays the essential role substantially. The dye that was first used in the Grätzel cell is a ruthenium (Ru) bipyridine complex with a carboxyl group. This dye can efficiently absorb visible light in a wavelength range of up to 800 nm. The carboxyl group provides chemical bonding to the surfaces of titanium oxide particles. The resulting advantage was the smooth injection of electrons from the dye to the titanium oxide.[22] Figure 5 shows the action spectrum of dye-sensitized cells with different ruthenium (Ru) dyes. Professor Grätzel et al. then changed the substituent group and found a dye commonly called black dye, which absorbs the spectrum of up to 900 nm with a photoelectric conversion efficiency as high as 80% for incident monochromatic light. The cell using this dye records the highest performance at present. Since ruthenium is an expensive metal, ruthenium-free dyes have also been developed. However, no dye has been reported to surpass ruthenium in performance. It should be noted that AIST (Professor Arakawa et al., currently at Tokyo University of Science) presented a coumarin organic dye that contains no metallic element and exhibits a conversion efficiency of around 8%. A carbazole dye presented by AIST senior researcher Hara et al. provides an improved cell conversion efficiency and longer life.[23] Studies have also been made on the stability of the dye. Ruthenium dyes have a turnover (the possible number of photovoltaic conversions per dye molecule) of above ten million, which compares with ten years of light irradiation.[24]

(3) Electrolyte

The electrolyte in a dye-sensitized solar cell has a redox potential that determines the potential of the cell's positive electrode. The electrolyte is indispensable for the sake of electron transfer in the electrolyte, based on the physical diffusion of redox pairs. The highest conversion efficiency ever has been achieved by an electrolyte solution of acetonitrile in which iodine ions and iodine are dissolved. Having a low evaporating pressure, acetonitrile is prone to evaporation and drops in the conversion efficiency at high temperatures or with long-term use. Techniques for sealing the electrolyte in the cell have thus been developed. The solidification of the electrolyte is also required due to concern about physical damage to the cell. A quasi-solid electrolyte made of a combination of a nonvolatile ionic liquid and a gel with a conversion efficiency of above 7% was reported (Professor Hayase et al. at Kyushu Institute of Technology).[25] Aiming at a fully solid electrolyte, there have been researches on the use of inorganic compounds such as CuI and CuSCN, conductive polymers such as polypyrrole, low-molecular materials such as Triphenyldiamine, and amorphous organic compounds such as OMe-TAD.

(4) Counter Electrode

The counter electrode plays the role of returning electrons that are generated at the photo-electrode and delivered through the external circuit, back to the electrolyte. Since the electrolyte is corrosive, the counter electrode requires high corrosion resistance as well as a high reaction rate when reducing iodine in the electrolyte to an iodide ion. Considering the balance between these factors, a conductive glass electrode coated with platinum (Pt) has been used heretofore. Carbon electrodes and conductive polymers have been examined as an alternative to expensive Pt, whereas such materials do not come up to Pt in terms of the reduction rate.

(5) Cell encapsulation/modularization

For a better dye-sensitized solar cell, it is understandably necessary to improve the overall performance of the cell device. Dr. Han of Sharp Corporation (currently of the National Institute for Materials Science) et al. clarified the losses in the respective components of a cell by an internal resistance analysis, and achieved the world's highest performance at present through loss-reducing approaches.[26] AIST ((then) Managing Director Sugihara et al.) successfully improved the conversion efficiency up to 11% by stacking a plurality of cells in tandem.[27] Attempts to improve efficiency were also made to encapsulate a cell with optical nanofibers.[28] The glass substrate can be replaced with plastic to add flexibility to the cell (Professor Miyasaka et al. at Toin University of Yokohama).

For higher output, solar cells need to have an increased area for light reception. A single cell of a greater size, however, typically has a higher substrate resistance with a significant drop in output per unit area. This requires more than one cell to be connected for upsizing (modularization). Various methods have been examined to connect cells to each other. A module with connecting grids achieved a conversion efficiency of 9.0% (Professor Arakawa et al. at Tokyo University of Science).[29]

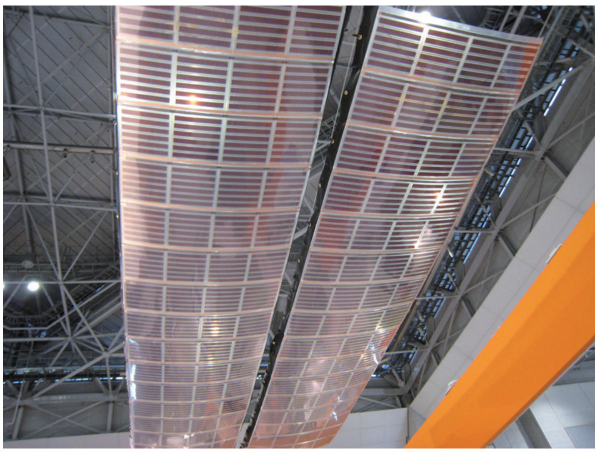
For cell and module stabilities, a single small cell that is stable under simulated solar light for more than 7000 hours was reported.[30] Figure 6 shows prototype examples of a module with a plastic substrate[31] (Peccell Technologies, Inc.) and a large module for outdoor use[32] (Fujikura Ltd.).

3-2 Technological Challenges for the Future and Measures of Dye-sensitized Solar Cells

Future challenges in technological development for dye-sensitized solar cells are summarized in the following three points.

1) Improved energy conversion efficiency

Much is still unknown about the sources of loss, including the reaction mechanism. To improve the conversion efficiency, it is first necessary to discover a dye that can increase the number of photons absorbed and the range of absorption in the solar spectrum. It is also important to match the redox




Plastic substrate module (left) and large module for outdoor use (right)

Figure 6 : Prototype Examples of Dye-Sensitized Solar Cell Modules

Source: Reference[32]

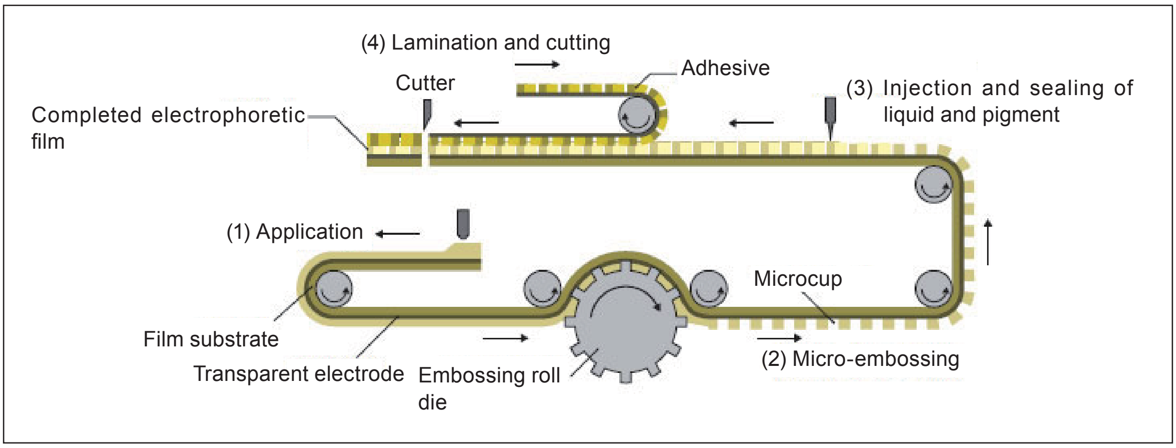
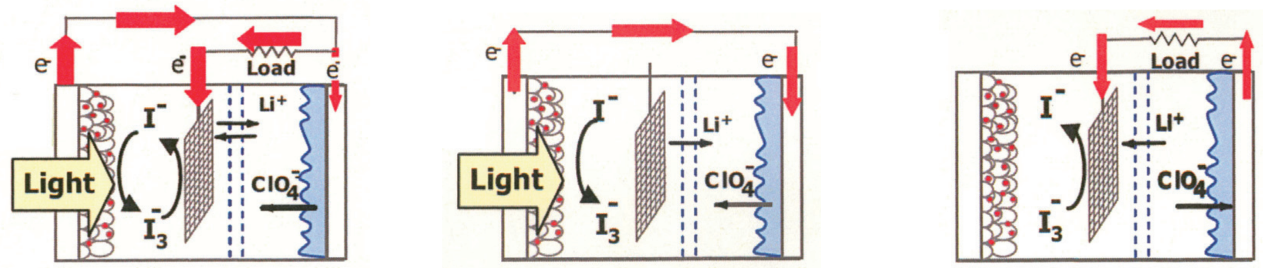


Figure 7 : Example of Roll-to-Roll Process for Electronic Paper

Source: Reference[34]



(Left: photovoltaic generation; center: photovoltaic charge; right: discharge)

Figure 8 : Principle of Operation of Dye-Sensitive Solar Cell That Can Store Energy

Source: Reference[35]

potential of the electrolyte to that of the dye. For research and development, computational simulation can be effectively used to design optimum dyes and electrolytes. Meanwhile, one of the approaches considered to be effective in designing the photo-electrode, including the dye, is to clarify the relationship between the structure and properties of the electrode materials and the charge-transfer mechanism,[33] and design the optimum electrode structure. As for the counter electrode, it is necessary to clarify the relationship between the corrosion behavior of candidate materials in the electrolyte and the catalyst activity of the reduction reaction of the electrolyte, and narrow down the candidate materials. Such development needs to be followed by optimization of light management in which the light confinement effect of the photo-electrode is extended to a cell level, including the glass substrate, electrolyte, and counter electrode. To improve module efficiency, sophisticated module design and fine processing technologies are also needed.

2) Long-term reliability

In view of reliability and long-term stability, it is desired to verify and improve the cell conversion efficiency and durability. An established method of making a contact at the interfaces between the electrolyte and the electrodes is required for a solidified electrolyte in particular. The mechanism of dye desorption and the mechanism of reaction of the electrolyte's composition change, which contribute to degraded long-term stability of a dye-sensitized solar cell, also require further elucidation.

3) Higher throughput

As employed herein, the throughput refers to the amount of products that are produced from raw materials in a given time. The cell production process provides improved throughput by virtue of the advantage of using no vacuum system. A roll-to-roll process is being considered. For example, a circuit pattern is printed on a roll of substrate as large as several hundreds of meters in length and around 1 m in width. The substrate is laminated with a roll of sealing film or the like before being rewound

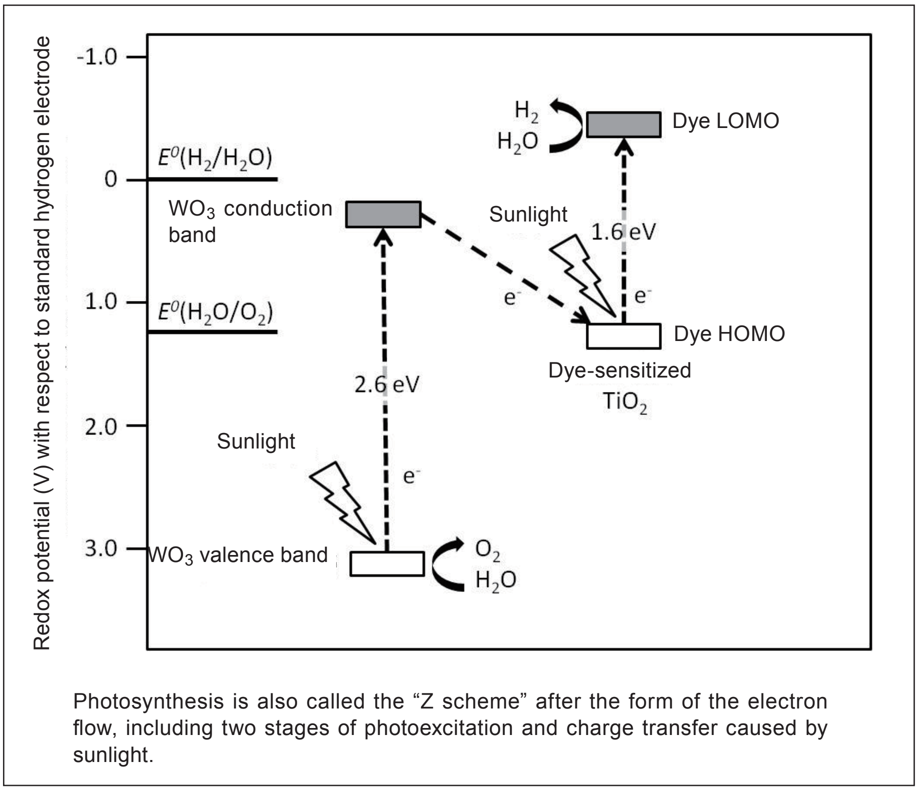


Figure 9 : Mechanism of Water Decomposition Reaction Simulating Two Stages of Photoexcitation and Charge Transfer

Prepared by the STFC based on Reference[36]

on another reel. The substrate is passed through the production machines continuously. The mutual connection of the production machines significantly saves the labor and devices for transportation. Figure 7 shows an example of a roll-to-roll process for electronic paper.[34]

The cold film formation of the photo-electrode can be effectively combined with print-based fine patterning. The process of absorption of the dye into titanium oxide, which is the key to the electrode production, also needs to be clarified for the sake of faster production processes.

3-3 Other Developments

Photochemical cells in general, including dye-sensitized solar cells, are characterized by how the photoelectric conversion reaction involves a redox reaction. Taking advantage of the characteristic, electrons or holes occurring from the electrodes or ions in the electrolyte can be utilized to implement a charge-storing function, like a secondary battery or capacitor in the solar cells. This means the possibility of achieving power assurance in the dark within a single cell, which is one of the challenges common to all solar cells.

Figure 8 shows the principle of operation that is proposed as an energy storable dye-sensitized solar cell (Professor Segawa at Tokyo University).[35] In this example, the dye-sensitized solar cell includes a conductive polymer charge storable electrode aside from the ordinary photo-electrode and counter electrode. Photovoltaic function is performed between the photo-electrode and the counter electrode as in ordinary dye-sensitized solar cells. For charging, the photo-electrode and the charge storable electrode are connected so that electrons occurring from the photo-electrode are accumulated into the charge storable electrode through an external circuit. With the accumulation of electrons in the charge storable electrode, anions are released into the electrolyte to maintain the charge balance. For discharge, the charge storable electrode and the counter electrode are connected to discharge electrons from the charge storable electrode while anions are accumulated again. The discharged electrons are passed through the external circuit, and consumed in the counter electrode for the reduction reaction of iodide ions in the electrolyte.

If a system can be constructed so that the electrons exchanged between the cell electrodes through the external circuit are consumed by new electrochemical reactions at the respective electrodes, then an artificial photosynthesis may become possible. For example, Figure 9 shows the mechanism of a water decomposition reaction that simulates two stages of photoexcitation and charge transfer, which are among the characteristics of photosynthesis, using a dye-sensitized titanium oxide (TiO_2) electrode (by Professor Grätzel).[36] The first stage of photoexcitation reaction at the tungsten oxide (WO_3) electrode initially produces an electron and a hole. The hole decomposes water into oxygen. The electron is transported through the medium within the same system (such as ions in the solution) to reach the dye-sensitized TiO_2 electrode. The electron at the dye-sensitized TiO_2 electrode is raised to a higher energy level by the second stage of photoexcitation reaction, whereby water is decomposed into hydrogen. The two stages of photoexcitation and charge transfer are referred to as “Z scheme” since they look like “Z” sideways. To achieve this artificial photosynthesis, it is necessary to improve the efficiency of the light-based charge separation, develop a medium that transports charges within the system with high efficiency, and develop an electrode catalyst that promotes the CO_2 reduction reaction.

4 Conclusion

In view of the photovoltaic generation discussed in Chapter 1, dye-sensitized solar cells have the following potentials:

1) Improved cost efficiency of solar cell modules, including cost reduction

Dye-sensitized solar cells require no vacuum system for manufacturing, and thus have an essential advantage in terms of production cost. There is still a lot of room for improvement in the photoelectric conversion efficiency. A significant improvement in the cost efficiency of solar cell modules can be expected.

2) Transformation into usable energy for the sake of expanded use and applications

Using various types of dyes, dye-sensitized solar cells have wide color variations for excellent decorative potential. The photovoltaic phenomenon in a dye-sensitized solar cell involves a redox reaction, and the ions involved can be used for the development of an energy storable solar cell and artificial photosynthesis.

3) Fostering of social infrastructures, use infrastructures, and use environment

Dye-sensitized solar cells contain no toxic substance as a cell component material. The materials are relatively easy to separate and recover, which is advantageous in view of a recycling and reuse framework for solar cell panels.

4) Industrial evolution and international competitiveness

There is as yet no particular problem in procuring the raw materials of dye-sensitized solar cells from overseas markets. The Asian regions have a background suited for introducing the monozukuri technologies, which is advantageous to the development of production bases in Asia. Japan's superior capabilities for research and development of materials and nanotechnologies can be utilized to secure international competitiveness of the product technologies on dye-sensitized solar cells.

Dye-sensitized solar cells are collections of various technologies. The distinct characteristics, unlike those of other solar cells, require a broader spectrum of views and ideas in terms of research and development and the way of applications. For the sake of improved cell characteristics and industrial evolution, various fields of specialization therefore need to be merged. One good example is the integration between amorphous silicon, which accepts all types of base materials, and the plastic thin film technologies, whereby an amorphous solar cell film of little thickness, light weight, and high flexibility was successfully developed.[37] Dye-sensitized solar cells are expected to benefit from the exchange of researchers between research fields such as organic complex chemistry and micromechanics, and electrochemistry and chemical engineering, to name a few. The fields of materials and print engineering can be integrated for improved production efficiency. Cell module designers and interior designers can cooperate to broaden the applications, taking advantage of the dye-sensitized solar cells. Such integration of different fields of specialization requires mediators and intermediary settings. I hope for more frameworks to facilitate exchanges among researchers, engineers, and people who are capable of setting the directions of research and development.

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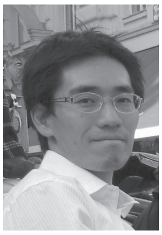
Profile



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